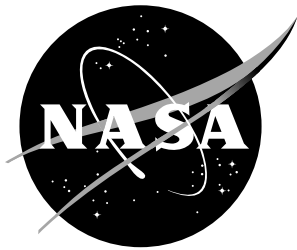


Acoustic Emission Monitoring of the DC-XA Composite Liquid Hydrogen Tank During Structural Testing

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TECHNICAL MEMORANDUM

ACOUSTIC EMISSION MONITORING OF THE DC-XA COMPOSITE LIQUID HYDROGEN TANK DURING STRUCTURAL TESTING

I. INTRODUCTION

As part of the reusable launch vehicle program, McDonnell Douglas built a composite liquid hydrogen tank to be used as the flight tank on the DC-XA vehicle. The tank, 8 ft (2.43 m) in diameter and 16 ft (4.88 m) long, underwent structural testing at the Marshall Space Flight Center. Acoustic emission (AE) monitoring of the structure was included in the monitoring and inspection techniques.

The purpose of using AE during structural testing was to monitor the tank for acoustic indications of structural damage in two areas: the central joint and the repair area on the forward dome. This test was also used to establish and verify techniques for using AE on cryogenic fuel tanks.

II. PROCEDURE

A total of 18 AE transducers were bonded to the tank in three areas. All transducers and pre-amplifiers were manufactured by Physical Acoustics and were bonded with Hysol EA 9394 adhesive. Sensor and adhesive selection was based primarily on their ability to withstand the thermal environment that would be encountered during the test. Twelve model S9215 AE transducers were bonded, equally spaced, to the central joint of the tank. Two S9215's were bonded to the forward dome, 10 inches apart on either side of the repair area. Also included in this test were four transducers from Rockwell International. These transducers were used to establish and verify AE techniques as part of Rockwell's effort to develop a flight AE system that would be incorporated onto the DC-XA. Two model D9215 transducers and a model PICO transducer were bonded in a triangular array, 10 inches per side, just above the lower Y joint, where the lower skirt was bonded to the tank. A model Mini-30 transducer was bonded inside the array. Each transducer was connected to a model 1220A preamplifier with a gain setting of 60 dB. The system used to collect data was a Physical Acoustics model Spartan AT supported by a PC.

Three location groups were identified: linear location between the two transducers on the dome, linear location between each pair of transducers around the central joint, and triangular location within the triangular array above the Y joint. Each transducer was checked by pencil lead break tests to verify that the transducer was working. Each location group was checked by pencil lead break tests to verify that the group was locating accurately. The system parameters are described in table 1.

Table 1. AE system settings.

AE Parameters	
Peak Definition Time	100 μ s
Hit Definition Time	200 μ s
Hit Lockout Time	500 μ s
Total System Gain	60 dB
Threshold	60 dB

The structural tests were conducted in three groups: applied loads and pressures at ambient temperature; applied loads and pressures at cryogenic temperature; and fill, pressurize, and drain tests using liquid hydrogen. Table 2 shows the test labels for the ambient temperature and liquid nitrogen cases. For this test, the maximum expected operating pressure (MEOP) was 53.6 lb/in² (369.6 kPa). The limit load in tension was 67,775 lbf (301.6 kN) and in compression was 88,560 lbf (394.1 kN).

Table 2. Test identifiers.

Test Identifier	Test Description
A1PT	Ambient temperature, tensile load to 40 percent limit, pressure to 40 percent MEOP
A2PT	Ambient temperature, tensile load to 110 percent limit, pressure to 140 percent MEOP
A1PC	Ambient temperature, compressive load to 40 percent limit, pressure to 40 percent MEOP
A3PC/A4C	Ambient temperature, compressive load to 110 percent limit, pressure to 140 percent MEOP
C1PC	Liquid nitrogen-filled, compressive load to 40 percent limit, pressure to 40 percent MEOP
C3PC	Liquid nitrogen-filled, compressive load to 140 percent limit, pressure to 110 percent MEOP
C1PT/C2PT	Liquid nitrogen-filled, tensile load to 110 percent limit, pressure to 140 percent MEOP

III. TEST RESULTS

A. Ambient Temperature Tests

The first attempt at ambient temperature testing was conducted with the preamplifier gain set to 60 dB. As the data were being collected, it was apparent that the 60 dB setting was too high. Emissions from purge lines and other nontest-related sources were being detected, making the data useless. The first attempt at A1PT ended prematurely, allowing the preamplifier gain to be reset to 40 dB.

The second attempt to complete case A1PT ended when the load lines failed at 36 percent of limit load and 31 percent of the MEOP. Case A1PT was completed on the third attempt. Testing and AE data collection proceeded without incident until equipment failure rendered the data from A3PC/A4C useless. AE hit data for the ambient cases is tabulated in table 3.

Table 3. Number of AE hits for ambient temperature tests.

Test Identifier	Number of AE Hits
A1PT second attempt	41558
A1PT third attempt	111
A2PT	31368
A1PC	56
A3PC/A4C	Data Lost

Although a large number of acoustic hits were recorded, they were mainly of low amplitude and short duration. This activity can be attributed to crazing in the resin material. Also, the low number of hits on the final run of A1PT and on A1PC indicates that the tank is following an AE principle known as the Kaiser effect. The Kaiser effect states that a structure is acoustically active only the first time it is loaded to

a given state. The Kaiser effect is not an axiom, but a useful rule of thumb that generally indicates structural problems when it is not present. The presence of the Kaiser effect in this structure is shown graphically in figure 1. As the pressure increases, the acoustic activity remains negligible until the pressure passes the 21 lb/in² point, the highest pressure from previous tests.

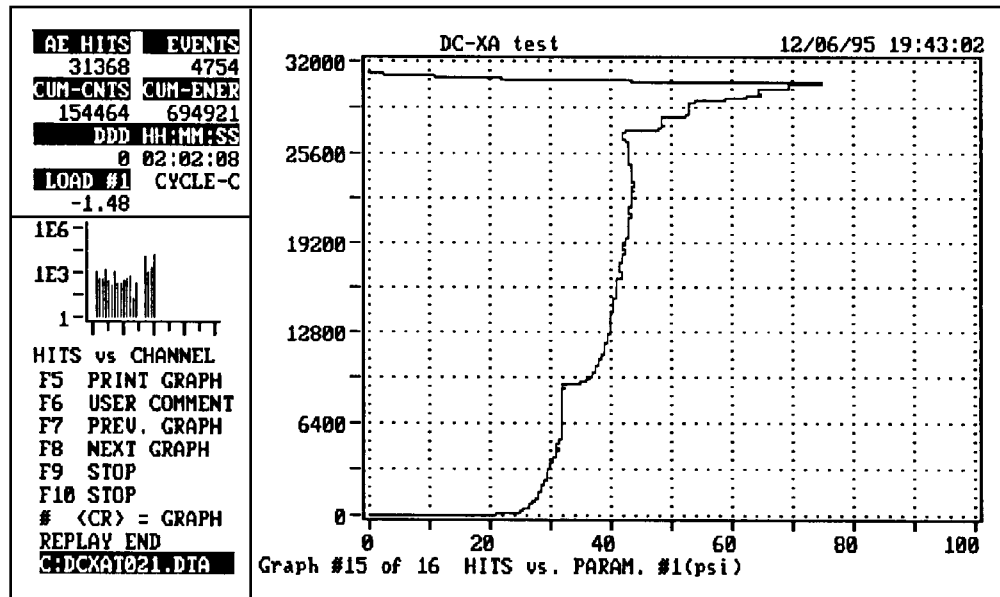


Figure 1. Cumulative acoustic hits versus pressure (lb/in²).

B. Cryogenic Tests

The cryogenic test series started with a liquid nitrogen fill and drain of the tank with no induced loads or pressures. The fill generated 13,832 acoustic hits of principally low amplitude and short duration. The second fill of the tank generated similar results, indicating that the Kaiser effect may not be particularly useful for evaluating tests performed at cryogenic temperatures. Table 4 shows the AE hits for the liquid nitrogen and liquid hydrogen tests.

Table 4. Number of AE hits for liquid nitrogen tests.

Test Identifier	Number of AE Hits
First liquid nitrogen fill	13,832
Second liquid nitrogen fill	9,435
C1PC	200,000+
C3PC	200,000+
C1PT/C2PT	No data
Leak Check	19

Despite the large amount of data recorded during this phase of the testing, little can be deduced from it. The two tests differ from the two fills only in the number of hits. The proportion and distribution of the hits with respect to amplitude and duration remains similar. Most of the acoustic activity during C1PC and C3PC appears to result from interaction of liquid nitrogen with the internal insulation. Each time the pressure was increased, there was a surge of acoustic activity that continued for some time after the pressure had stabilized. The most meaningful data from this set are from the leak check that was performed after the completion of all liquid nitrogen testing. The tank was pressurized to 54 lb/in², and the lack of acoustic activity during this check indicates structural soundness.

The last procedures performed were flight operations simulations using liquid hydrogen pressurized to 100-percent MEOP. The AE's during these tests were similar to the emissions from the liquid nitrogen tests. There were no indications of structural problems. The emissions continued after the pressure stabilized, suggesting that the activity resulted from the interaction of liquid hydrogen with internal insulation. Figures 2 and 3 show this phenomenon.

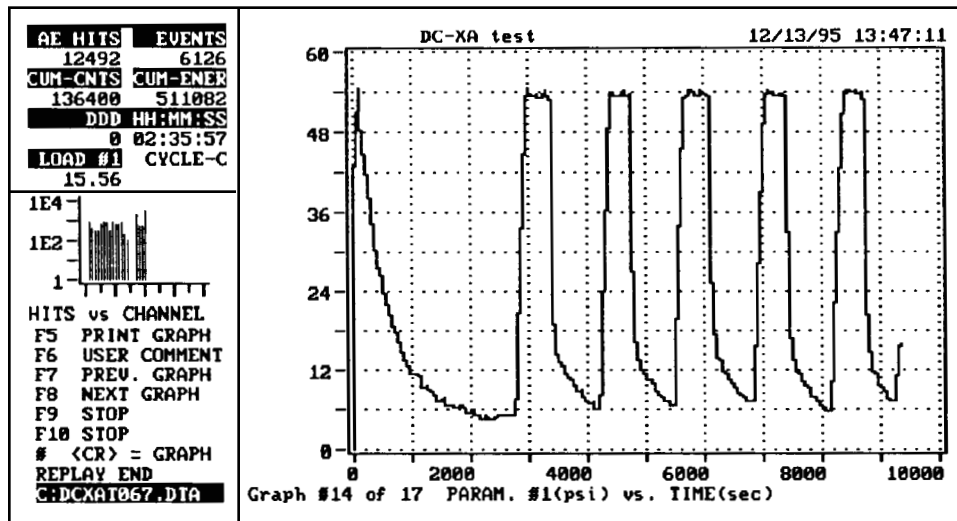


Figure 2. Pressure versus time for the flight operations simulation test.

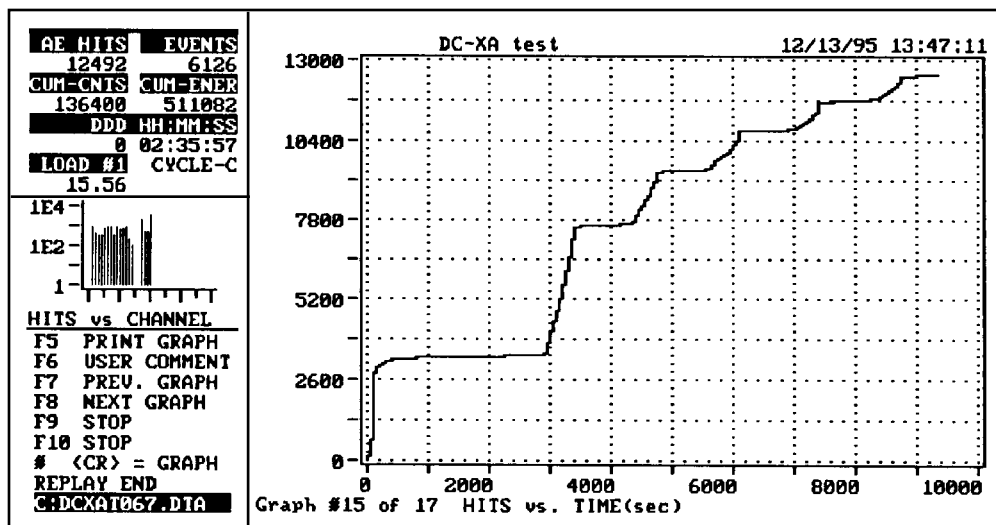


Figure 3. Cumulative acoustic hits versus time for the flight operations simulation test.

IV. CONCLUSIONS

AE gave no indication of damage to the tank at the locations monitored. All transducers withstood the exposure to low temperatures. The adhesive bonds holding the transducers to the tank also remained intact, although the question has arisen that some of the acoustic activity may have originated in the adhe-

sive. Although the basic techniques for performing AE on this type of structure were verified, considerable work remains before a standard technique is developed.

V. RECOMMENDATIONS

As a result of data analysis and actual test performance, the following recommendations are made:

1. For AE to provide meaningful test results, a more thorough understanding of the article being tested is essential. Specific knowledge of the construction techniques and materials used or present in the structure is required. This could be accomplished by integrating nondestructive evaluation more fully into the manufacturing and design process.
2. A thorough knowledge of the test plan is essential to properly set up AE monitoring of a test. Minor modifications to the test plan should be considered to enhance the usefulness of AE data.
3. No structure should be tested without either a data base of previous tests on similar structures and materials or a series of subcomponent tests leading up to the final structure. The use of AE should be planned well in advance of the final phase of testing to accommodate this requirement.
4. Further investigation into the use of AE at cryogenic temperatures should be undertaken. Issues investigated should include thermal effects on piezoelectric sensors, selection of frequency range to monitor, adhesives used to bond transducers, and the characterization of signals taken from a cryogenic environment.